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Study of the electromechanical properties of aligned carbon nanotubes coated with ZnO using atomic force microscopy

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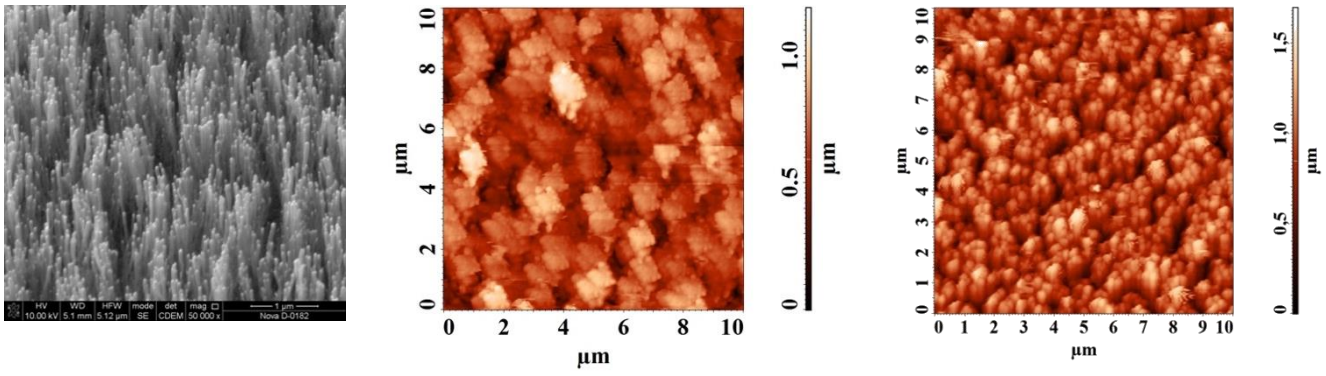
Aligned carbon nanotubes (CNTs) are one of the most promising materials for creating nanoelectronics and nanopiezotronics devices due to the unique memristive and piezoelectric properties [1, 2]. Studies of the effect of a piezoelectric coating on the properties of CNTs are of particular interest. Moreover, the study of electromechanical parameters of aligned CNTs by scanning probe microscopy is a nontrivial task due to their mobility during scanning [3].

The aim of this work is to study the effect of a conformal ZnO coating on the geometric parameters and the piezoelectric response of aligned carbon nanotubes by atomic force microscopy (AFM).

As the experimental sample was used vertically aligned CNTs array grown by plasma enhanced chemical vapor deposition on a silicon wafer with TiN bottom electrode on the surface. The diameter, height and density CNTs in array were 42 nm, 2.6 μm and 82 μm^{-2}, respectively (Fig. 1a). The conformal deposition of the ZnO films was carried out at laser radiation energy of 160 mJ and a pulse number of 10 000 with a repetition rate of 10 Hz using a Pioneer 180 (Neocera Co., USA). Surface studies of the CNT array were performed by the AFM in the semicontact mode using the Ntegra probe nanolaboratory (NT-MDT, Russia). A commercial cantilever with a platinum coating NSG11/Pt was used as the AFM probe. The AFM images of the CNT array before and after the deposition of ZnO are shown in Fig.1b and Fig. 1c respectively. Studies of the piezoelectric response of CNTs were carried out on the basis of the previously developed technique [2]. The results of the study of the piezoelectric response of CNTs before and after ZnO coating are shown in Fig. 2.



a b c

Figure 1. Experimental sample of vertically aligned CNT array: (a) SEM image; (b, c) AFM images before and after ZnO coating, respectively.

Studies of the experimental sample by the scanning electron microscopy showed no visible changes before and after the deposition of the ZnO film, which suggests that the deposition is conformal. In this study by the AFM method showed clear differences. Thus, the analysis of AFM images obtained before and after the deposition of ZnO showed that pure CNTs are combined into bundles with a diameter of 1 μm under the action of van der Waals forces when scanning in the semicontact mode (Fig. 1b). When scanning CNTs coated with ZnO bundling does not occur (Fig. 1c). This is due to the simultaneous decrease in the van der Waals forces arising between CNTs conformally coated with ZnO and an increase in bending stiffness of CNTs due to the coating. As a result, the elastic forces arising in the nanotubes during the formation of the bundle become larger than the van der Waals forces and no bundles are formed.

Studies of the piezoelectric response of CNTs before and after deposition of ZnO have shown that in both cases a piezoelectric current arises when the nanotube is deformed (Fig. 2). In this

case, prior to deposition, a piezoelectric current of up to 14 nA is detected immediately upon approaching a CNT bundle (Fig. 2a), due to the fact that nanotubes have strain when combined into a bundle [2]. The current value slightly increases (up to 17 nA) during a further deformation of a CNT bundle by the force spectroscopy AFM. The piezoelectric current is absent when approaching a CNT conformally coated with ZnO (Fig. 2b). However, a current of up to 22 nA arises with further deformation of the coated CNT (Fig. 2b). The magnitude of the detected current increases as compared with pure CNTs, which may be due both to a change in the type of deformation of the CNT from bending to compression, and to the influence of the ZnO piezoelectric coating.

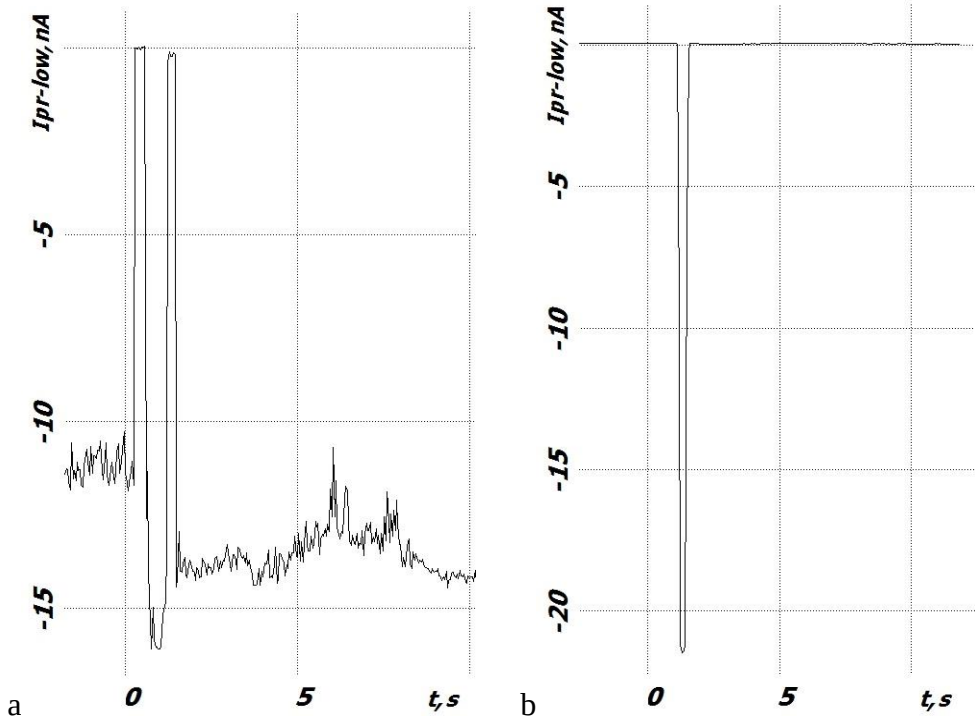


Figure 2. The current-time dependences of the deformation process of CNTs before (a) and after (b) coating with ZnO.

Thus, it has been shown that the conformal coating of ZnO leads to an increase in the bending stiffness of CNTs, as a result of which CNT bundles are not formed during the AFM scanning. In this case, the piezoelectric response of CNTs is increased by more than 35%. The obtained results can be used to develop and creation of nanoelectronics devices based on vertically aligned CNTs in particular sensors and adhesion coatings. The results were obtained using the equipment of the Research and Education Center and the Center for collective use "Nanotechnologies" of Southern Federal University.

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